Making the best of both worlds: Can high-resolution agricultural administrative data support the assessment of High Nature Value farmlands across Europe?

Lomba, A; Strohbach, M; Jerrentrup, JS; Dauber, J; Klimek, S; McCracken, DI

Published in:
Ecological Indicators

DOI:
10.1016/j.ecolind.2016.08.008

First published: 13/08/2016

Document Version
Peer reviewed version

Citation for pulished version (APA):
Lomba, A., Strohbach, M., Jerrentrup, JS., Dauber, J., Klimek, S., & McCracken, DI. (2016). Making the best of both worlds: Can high-resolution agricultural administrative data support the assessment of High Nature Value farmlands across Europe? *Ecological Indicators*, *72*, 118 - 130. https://doi.org/10.1016/j.ecolind.2016.08.008

Title: Making the best of both worlds: can high-resolution agricultural administrative data support the assessment of High Nature Value farmlands across Europe?

Lomba, A.[1,2], Strohbach, Michael[3,4], Jerrentrup, J. Sabrina[4], Dauber, J.[4], Klimek, Sebastian[4], McCracken, Davy I.[2]

[1] CIBIO/Inbio, Centro de Investigação em Biodiversidade e Recursos Genéticos da Universidade do Porto, Campus Agrário de Vairão, R. Padre Armando Quintas, nº 7, 4485-661 Vairão, Portugal

[2] Hill & Mountain Research Centre, Scotland's Rural College, Kirkton Farm, Crianlarich FK20 8RU UK

[3] Humboldt-Universität zu Berlin, Department of Geography, Unter den Linden 6, 10099 Berlin, Germany

[4] Thünen Institute of Biodiversity, Bundesallee 50, 38116 Braunschweig, Germany

Corresponding author: Angela Lomba

Address: CIBIO/Inbio, Centro de Investigação em Biodiversidade e Recursos Genéticos da Universidade do Porto, Campus Agrário de Vairão, R. Padre Armando Quintas, nº 7, 4485-661 Vairão, Portugal

E-mail: angelalomba@fc.up.pt

Abstract

Worldwide, the role of farmlands for biodiversity conservation and the delivery of multiple ecosystem services has been widely acknowledged. In the European Union (EU), societal demands to include environmental conservation concerns within the Common Agricultural Policy (CAP) has resulted in the recognition of the importance of maintaining High Nature Value farmlands (HNVf).

HNVf constitute complex social-ecological systems, which owe their nature conservation value to the maintenance of specific, mostly low-intensity farming systems, supporting high levels of species and habitats dependent on agricultural practices. Even though HNVf assessment in space and time is essential to evaluate the effectiveness of Rural Development Programmes, the diversity of rural landscapes across EU, the scarcity of data on farming systems, and the lack of common methodological guidelines has hampered the implementation of HNVf mapping and monitoring across Europe. Thus, there is a pressing need to develop and test methodological approaches that may support HNVf assessment across the EU.

The Integrated Administration and Control System (IACS) which is mandatory for all EU Member States constitutes a system for the management and control of CAP payments to farmers. Essentially, IACS comprises high-resolution, spatially explicit information on the type and intensity of agricultural land-use. Even though such data has been referred as exhibiting high thematic, spatial and temporal resolution, IACS has seldom been used, due to significant access restrictions. Here, the potential to use IACS data to support the assessment of HNVf was evaluated within the German Federal State of Lower Saxony by implementing a recently developed methodological framework. Sets of indicators known to be essential for identifying potential HNVf and underlying farming systems (expressing landscape structure and composition, farming systems, and

crop diversity), were derived from IACS. Spatial patterns of indicators were analyzed at two different scales to delineate the potential distribution of HNVf across Lower Saxony.

Results highlighted that most regions in Lower Saxony were characterized by intensive farming practices including high livestock density, high share of intensive crops and low density of linear elements. Only 3% of the Utilized Agricultural Area (UAA) of Lower Saxony potentially constituted HNVf, with the majority of HNVf coinciding with mosaics of arable and/or permanent crops and semi-natural features under less intensive farming practices. Semi-natural grasslands, partially under agri-environment scheme management contracts, covered roughly 1% of the UAA and were mostly intermingled with other farmland habitats in extensively managed agricultural landscapes.

In the context of the EU-wide HNVf assessment, IACS constitutes an important source of data, characterized by a high spatial, thematic and temporal resolution of data collected annually. Whilst having the potential for use in HNVf assessment, some challenges remain, especially due to significant access restrictions. Nevertheless, IACS constitutes a powerful tool to evaluate the extent and condition of HNVf across the EU countryside. Making use of IACS data in such a way could provide a stepping-stone towards achieving a more effective balance between the management and control of CAP support payments and the growing societal demands related to the maintenance and enhancement of farmland biodiversity and ecosystem services.

Keywords (4-6)

Agro-biodiversity; Common Agricultural Policy (CAP); Indicators; Integrated Administration and Control System (IACS); Land-sharing; Rural Development Programmes (RDP)

1. Introduction

Globally, an expansion and intensification of agricultural land has occurred in the last century (Wade *et al.*, 2008), with negative impacts on the environment and related natural resources, such as biodiversity and ecosystem services (Millennium Ecosystem Assessment, 2005; Aviron *et al.*, 2009; Shackelford *et al.*, 2015). Driven mainly by economic, political and demographic processes, agricultural land in Europe has been facing two opposite trajectories: either abandonment of economically marginal remote and upland areas or the intensification of farming practices in the more productive lowland areas (MacDonald *et al.*, 2000; Stoate *et al.*, 2009; Baudron and Giller, 2014; Beilin *et al.*, 2014; van Vliet *et al.*, 2015).

While high yield farming is considered to be among the most damaging human-related activities to wildlife (Balmford *et al.*, 2012; Shackelford *et al.*, 2015), the importance of agricultural land for biodiversity maintenance and long–term conservation, and the provision of ecosystem services, e.g., carbon sequestration, aesthetic landscapes, and support of biodiversity, has also been acknowledged (Swinton *et al.*, 2007; Power, 2010). Farming has been shaping European landscapes for centuries or even millennia and up to 50% of all species rely, to some extent, on agricultural ecosystems and habitats, including endemic and threatened species (Bignal and McCracken, 1996; Halada *et al.*, 2011; Lomba *et al.*, 2014). The role of traditional, low-intensity farmland for the maintenance of natural capital and protection of the countryside has thus been debated, ultimately developing into the 'High Nature Value farmlands' (HNVf) concept (Egan and Mortensen, 2012; Plieninger and Bieling, 2013; Renwick *et al.*, 2013; Lomba *et al.*, 2014; Lomba *et al.*, 2015; Strohbach *et al.*, 2015).

The HNVf concept was developed within the European Union (EU) to characterize agriculture-dominated landscapes where high nature and/ or conservation value is dependent on the continuation of specific low-intensity farming systems (Beaufoy *et al.*, 1994; Andersen *et al.*, 2003; Lomba *et al.*, 2014). These farming systems constitute complex socio-ecological systems resulting from a long-term relationship between human activity and the surrounding environment (Plieninger and Bieling, 2012; Plieninger and Bieling, 2013). The intrinsic nature value of HNV farmlands is due to the prevalence of low-intensity farming practices and either a high proportion of semi-natural vegetation e.g. pastures and meadows (referred to as HNVf type 1; Oppermann *et al.*, 2012), or the presence of small-scale elements in the agricultural landscapes, such as field margins, hedgerows and tree lines (referred to a HNVf type 2; Andersen *et al.*, 2003). In addition, some intensively managed farmlands have been considered as HNVf type 3 due to their importance for the maintenance and survival of some populations of agriculture-dependent species with conservation interest (e.g. farmland birds and reptiles; Andersen *et al.*, 2003).

In recognition of EU efforts towards sustainable rural development and land stewardship (Plieninger and Bieling, 2013), HNVf was included in the Common Monitoring and Evaluation Framework (CMEF) for the rural development policy within the context of the EU Common Agricultural Policy (CAP; EC, 2006). Their role for biodiversity conservation, provision of ecosystem services and public goods generated has also been highlighted within the EU Biodiversity strategy to 2020 (EEA, 2015). Nevertheless, the recent mid-term assessment of the EU Biodiversity strategy to 2020 reported that no relevant progress has been made towards the improvement of the conservation status of most agriculture-dependent species and habitats. The assessment recommended that greater and more effective efforts are urgently needed to increase the contribution that farmlands, including HNVf, make to the maintenance and enhancement of biodiversity in the European Union (EU) countryside (EC, 2015; EEA, 2015).

However, even though the assessment of HNVf indicators is mandatory across the EU, the diversity of rural landscapes, the scarcity of (suitable) datasets on biodiversity, land cover and land-use, and the lack of common guidelines and/or approaches for mapping HNVf are important obstacles towards its successful implementation (see e.g. Peppiette, 2011; Lomba *et al.*, 2014; Strohbach *et al.*, 2015).

Following the EU guidelines (Paracchini *et al.*, 2008; EENRD, 2009), Lomba *et al.* (2015) recently described a multi-step spatially-explicit framework to assess the extent of HNV farmlands in the EU countryside. In short, such approach builds on the spatially-explicit assemblage of indicators informing on the social-ecological dimensions underlying the nature value of such farming systems, namely landscape structure and composition, and the extensive character of farming practices (Lomba *et al.*, 2014; Lomba *et al.*, 2015). In addition, it has been recommended that indicators considered for HNVf assessment should be derived from the best spatial and/or temporal resolution available for the target area (Lomba *et al.*, 2015). Whilst this methodological framework has been shown to have a great potential to operationalize the HNVf concept, some important challenges remain, such as its application to other social-ecological contexts, datasets and scales across the EU countryside. Here, one of such challenges is tackled through the implementation framework using indicators derived from the Integrated Administration and Control System (IACS) database.

IACS, which was established in the early 1990s (EEC, 1992), mainly consists of high resolution, annually-updated farm-level information (e.g. livestock) and parcel-level information (e.g. crop type; Keenleyside *et al.*, 2014). Despite its availability across EU Member States, IACS data has seldom been used as a spatially-explicit dataset for indication and monitoring of HNVf, mainly due to access restrictions put in place to protect land manager privacy (Lomba *et al.*, 2014; Strohbach *et al.*, 2015). To-date, Steinmann and Dobers (2013) have analyzed patterns of crop rotation and sequence across the federal state of Lower Saxony based on the German IACS. The same database has been used by Nitsch *et al.* (2012) to assess land-use change between grasslands and arable land. In addition, Ribeiro *et al.* (2014) used IACS data to model HNV farming systems dynamics as response to policy change for a region in southern Portugal, the Austrian HNVf indicator relies on IACS data to incorporate information on land-use and agri-environment schemes, and the Scottish Government uses IACS data to estimate annual changes in extent and distribution of HNVf (AES; Bartel *et al.*, 2011; Scottish Government, 2011).

Here, we tested the potential of IACS data to support the assessment of HNVf using the German Federal State of Lower Saxony as case study. HNV farmlands assessment followed the multi-criteria framework recently described by Lomba *et al.* (2015), targeting HNVf types 1 and 2. Overall, HNVf assessment was built on a multi-criteria analysis of spatially-explicit indicators expressing landscape structure and composition, farming systems, and crop diversity (Landscape Elements, Extensive Practices and Crop Diversity sets of indicators; Lomba *et al.*, 2015), known to inform on relevant social-ecological components of HNV farming systems. Results are discussed in the context of Lower Saxony assessment and monitoring of HNVf and implications drawn with respect to High Nature Value farmlands assessment and monitoring across the EU.

2. Methods

2.1. Study area

The study area is situated in north-western Germany and covers the federal state of Lower Saxony (Fig. 1). Lower Saxony is Germany's second-largest federal state in terms of its area (ca. 47787 km^2) and includes 1041 local administrative units (LAU 2) corresponding to municipalities, the lowest level in the administrative structure of Germany. Total land area covered by each municipality ranges between 0.2 km^2 and 401.7 km^2 (mean: 45.9 km^2).

About 56% of total land area within Lower Saxony is used for agricultural production, consisting of arable land (including temporary grassland), permanent grassland and land under permanent crops, and ca. 22% is covered by forests. Less than 10% of the total land area is covered by urban areas. Arable land accounts for ca. 71% of the Utilized Agricultural Area (UAA), permanent grasslands make up 28% of the UAA and less than 1% is used for the production of permanent crops. There are, however, large regional differences in agricultural land-use and major crop type distributions across Lower Saxony.

Lower Saxony is located in a transition zone between a more maritime climate in the North-West and a more continental climate in the South and East. According to climatic, geomorphological, hydrological and soil characteristics Lower Saxony can roughly be divided into three major biogeographical regions. The coastal regions (Fig. 1C; 1) along the North Sea include the East Frisian Islands, mudflats and salt marshes with an average annual temperature of 9.4 °C and a mean precipitation of 814 mm in the period of 1981-2010 (DWD 2015). The lowlands (Fig. 1C; 2) are dominated by agricultural land-use with an average annual temperature of 9.4 °C and a mean precipitation of 769 mm. In the northwestern part of the lowlands more than half of the UAA is covered by highly productive permanent grassland (Smit *et al.*, 2008), with intensive dairy farming and zero-grazing ('stall feeding') dominating (Klimek *et al.*, 2014). The eastern part of the lowlands is characterized by cultivation of cereals and fragments of heathland. Most of these lowland heathland areas are designated as European special areas of conservation (SAC; e.g. ‘Lüneburger Heide’) and are mainly grazed by sheep with financial support from agri-environment schemes. Particularly in the western part of the lowlands, production of energy crops has emerged as a new agricultural activity in recent years, mainly at the expense of permanent grasslands. It has been shown that maize for bioenergy production was the dominant crop after the conversion of permanent grassland to arable land (Nitsch *et al.*, 2012). This region of the lowlands is dominated by intensive livestock production, particularly pig and poultry. The uplands (Fig. 1C; 3) in the southern part of Lower Saxony are characterized by a large proportion of arable land and forest, interposed with patchily distributed fragments of permanent grassland (Klimek *et al.*, 2007). The average precipitation is 832 mm, with a mean annual temperature of 9.0 °C. In the south, the Harz is the highest mountain range (up to 1141 m a.s.l.). The northern part of the uplands is characterized by fertile loess soils and highly-productive large-scale cereal-based farming systems.

#Fig. 1 approximately here#

2.2 Integrated Administration and Control System (IACS)

IACS consists of a number of interconnected databases, which provide an identification system for farmers and their payment entitlements, an identification and registration system for livestock, and an identification system for agricultural areas called the Land Parcel Identification System (LPIS) (EC, 1996; Sagris and Devos, 2009). LPIS is implemented differently across and even within EU member states (see Sagris and Devos, 2009 for details), and in the case of Lower Saxony, the so-called physical block representation, was adopted. According to this approach, agricultural parcels sharing a common boundary e.g. a ditch, footpath or forest edge, are grouped as a physical block. Agricultural parcels within each physical block may be property of one or more farmers, and thus be under different distinct land-use.

In the specific case of Lower Saxony, LPIS is available as polygons and was thus provided as an ESRI shapefile. Through a unique ID attributed to each physical block, it is possible to map IACS data across Lower Saxony. IACS includes two main levels of information: 1) type of land-use and size of agricultural parcels for which financial support was claimed; 2) farm-level information including the number and type of animals and farm type (organic/ conventional, fulltime /second income). Through the unique physical block ID, agricultural parcels can be linked to a single physical block and to a farm, even though the exact location of each agricultural parcel is not disclosed in this dataset to ensure land managers/owners’ privacy and data confidentiality.

2.3. Assessment of HNV farmlands using IACS data: spatially-explicit indicators and statistical analysis

HNVf assessment followed the methodological framework described by Lomba *et al.* (2015), and targeted specifically HNVf1, i.e. farmlands with high proportion of semi-natural habitats; and, HNVf2, i.e. landscape mosaics where small crop fields are intermingled with small-scale features. As HNVf3 nature value derives from the occurrence of individual species with high conservation interest (e.g. farmland bird species), often in intensively managed agricultural landscapes, such farmlands were not targeted in the context of this landscape-level research (Andersen *et al.*, 2003; Lomba *et al.*, 2014).

A multi-criteria approach was implemented using the three sets of spatially-explicit indicators defined by (Lomba *et al.* 2014, 2015): i) landscape elements, ii) extensive practices; and, iii) crop diversity. Whilst landscape elements set of indicators depict landscape structure and composition; indicators included within the extensive practices set reflect the intensity of farming practices; and, indicators on crop diversity, aim to inform the diversity of farming practices (Table 1; for detailed information regarding the approach implemented to calculate spatially-explicit indicators from IACS and LPIS data). All indicators related to farming systems were ascertained from IACS data for the year 2005 (Table 1). As IACS is restricted to agricultural land for which payments have been claimed, ancillary indicators derived from the German digital basic landscape model (Basis-DLM) were considered to enhance the accuracy of HNVf assessment whenever required (cf. Table 1).

Spatially-explicit patterns of targeted indicators were analyzed at two different scales: i) municipality (coincident with the local administrative unit, LAU 2; http://epp.eurostat.ec.europa.eu); and, ii) physical block. Analysis followed a sequential three step framework described below, which enabled the integration of high spatial resolution IACS data, while pursuing a landscape-level outcome (Fig. 2).

#Fig. 2 approximately here#

According to EU guidelines, the area of agricultural land covered by HNVf (i.e. HNVf baseline indicator, EENRD, 2009) should be expressed in relation to the utilized agricultural area (UAA). The Land Parcel Identification System (LPIS) provides highly disaggregated information on most agricultural landscapes (Nitsch *et al.*, 2012) and was used to comply with this EU recommendation. UAA was therefore determined as the sum of the area covered by physical blocks at the municipality level (coincident with the local administrative unit, LAU 2).

From the concept, a landscape-level approach seems to be appropriate to assess HNV farmlands (Beaufoy *et al.*, 1994; Andersen *et al.*, 2003; Lomba *et al.*, 2014). Accordingly, Step 1 comprised the definition of farmland dominance at the landscape level (Fig. 2). Farmland dominance was considered when two conditions were fulfilled: i) a value of 40% agricultural area (P.UAA) per municipality (rule of thumb proposed by Lomba *et al.*, 2015), and, ii) higher values for the share of agricultural cover ($P.UAA_m$) in relation to shares of urban ($P.Urban_m$) and forest areas, respectively ($P.Forest_m$; Table 1).

In Step 2, spatially-explicit patterns of indicators expressing the intensity of farming practices, specifically the livestock density index (LSI_m) and the share of intensive crops ($P.ICrops_m$), were analyzed (cf. Step 2, Fig. 2 and Table 1). Statistical results highlighted the most significant gradients of intensification underlying distinct farming systems and discriminated farmlands more likely to support high nature value in Lower Saxony, which were then considered for further analysis in Step 3 (Fig. 2, Table 1).

Finally, Step 3 aimed at targeting High Nature Value farmlands of types 1 and 2 in areas highlighted potential HNVf in Step 2. To accomplish this goal, analyses were performed at the municipality (Step 3a) and at the physical block (Step 3b) level (cf. Fig. 2, Step 3, and Table 1). Step 3a consisted on a detailed analysis of spatially-explicit patterns for the three sets of indicators (extensive farming practices, landscape elements and crop diversity sets of indicators; cf. Fig. 2, Step 3a, and Table 1). In Step 3b, a fine-scale analysis was implemented, combining results from Step 3a with high-resolution IACS data at the physical block level (Fig. 2, Step 3b). The fine-scale assessment of HNVf1 (Step 3b) was built on the assumption that in Lower Saxony, HNVf1 mainly consist of species-rich permanent grasslands (Oppermann *et al.*, 2012). Thus indicators informing on the share of permanent grasslands and the share of grasslands under agri-environment scheme were considered (cf. Table 1, Fig. 2). As for HNVf2 (step 3b), the share of intensive crops and crop diversity at the level of the physical block were considered to be suitable indicators (cf. Table 1 and Fig. 2).

All spatially-explicit analyses were conducted using the Spatial Statistics Toolbox for ArcGIS 10.3.1 Desktop (ESRI, 1999-2015). Spatial Autocorrelation analysis (Global Moran's I; ESRI, 1999-2015) was first applied to evaluate patterns (clustered, dispersed or random) exhibited by each of the considered spatially-explicit indicators at the municipality and physical block level (Table 1). For subsequent analyses only indicators found to exhibit clustered patterns, expressed as statistically-significant positive Moran's I index values, were considered. Spatially-explicit analysis of patterns for targeted indicators, in each of the steps formerly described (Fig. 2), except Step 3b, was performed using the Mapping Clusters toolset (ESRI, 1999-2015). To ensure that all groups include members that have natural neighbours, the Grouping Analysis tool was implemented with K-Nearest Neighbours as spatial constraints parameters. Outcomes included overall and within resulting group statistics, the discrimination ability of each indicator considered for analysis (expressed as higher R^2 values), and an evaluation of the optimal number of groups. Optimal number of groups outcomes are expressed as higher values for the pseudo F-statistic, and reflect a trade-off between the numbers of groups and indicators used in the analysis (Calinski-Harabasz pseudo F-statistic, hereafter F-statistic, assesses grouping effectiveness, and reflects within-group similarity and between-groups differences (c.f. ESRI, 1999-2015).

Step 3b (cf. Fig. 2) consisted on a spatially-explicit selection of physical blocks based on the analysis of variation of each indicator across targeted areas, whilst ensuring that the physical blocks identified as HNVf1 and 2 exhibited connectivity at the landscape-level. Thresholds were defined from spatially-explicit variation within each of the indicators in order to identify semi-natural grasslands embedded within farmlands under more extensive farming systems (HNVf1), or mosaics with high crop diversity and small-scale landscape features (HNVf2). The extent of HNVf corresponding to types 1 and 2 was addressed individually, assuming that both can coexist, depending on the characteristics of agricultural landscapes and underlying farming systems (Lomba *et al.*, 2014). Although analyses were performed at the physical block level, geometries are not disclosed to ensure privacy of managers and land owners, and protection of IACS data provided.

Indicators considered were tested for collinearity by Spearmans's rho index (ρ) using STATISTCA software (Statsoft, 2013), and a value of 0.7 was established as a maximum threshold for indicators to be included in the analysis (Dormann *et al.*, 2013). All values shown for indicators are expressed as mean ± standard deviation (SD).

#Table 1 approximately here#

3. Results

3.1. Dominance of farmlands across Lower Saxony

Lower Saxony has roughly ~2.7 million hectares of Utilized Agricultural Area, distributed across 1041 municipalities. Overall, agriculture constitutes a major land-use (62.84±12.11%, $P.UAA_m$) followed by forest and urban areas, with median values of cover of 16.83±12.14% and 9.27±5.99% respectively. Step 1 (for detailed description see section 2.3.), highlighted the dominance of farmlands on ~85% of Lower Saxony municipalities (n = 887). Table 2 shows the variation observed within spatially-explicit indicators considered for farmland-dominated municipalities.

#Table 2 approximately here#

3.2. High Nature Value farmlands across Lower Saxony

In Step 2, spatially-explicit indicators reflecting the extensive character of farming practices, LSI_m and $P.ICrops_m$, supported the discrimination of farmlands with high potential to support high nature value from non-HNV farmland (Fig. 3, Table 2). Grouping analysis resulted in the delineation of clusters A and B with 496 and 391 municipalities, respectively. Evaluation of the optimal number of groups was implemented within the Grouping Analysis toolbox, and ‘2’ highlighted as the most effective number of groups in relation to the indicators considered (expressed as the highest F-statistic value: 677.63; cf. methods section 2.4). Further analysis was based on R^2 values for the targeted indicators, which were found to be higher for the Livestock density index (R^2: 0.66) than for the Share of Intensive Crops (R^2: 0.19).

Variation of spatially-explicit indicators considered (Step 2) within resulting clusters depicted divergent patterns (cf. Table 3). Cluster (A) was found to exhibit higher values for the Livestock density index (LSI_m: 1.50±0.48) and lower values for the share of intensive crops ($P.ICrops_m$: 0.31±0.13). Conversely, lower values for LSI_m and higher values for the share of intensive were observed for cluster (B) (cf. Table 3). Similar trends were observed for the share of values within each cluster (cf. Table 3).

#Table 3 and Fig. 3 approximately here#

The joint analysis of values of R^2 observed for LSI_m and the internal variation of within-clusters indicators showed that the cluster (B) had greater potential to support farmlands with High Nature Value. Accordingly, Step 3a of the analysis focused on cluster (B) farmlands.

Step 3a was built upon grouping analysis of indicators expressing extensive farming practices, landscape elements and crop diversity. Supported by F-statistic values (F-statistic value: 120.57; cf. Table 4), three groups were considered to better discriminate variation of indicators across the targeted area (cluster (B) from Step 2; cf. Table 3). As presented in Table 4, R^2 values highlighted the share of intensive crops ($P.ICrops_m$; R^2= 0.66) and crop diversity (expressed as SEI_m; R^2=0.47) as indicators contributing most to within-clusters discrimination, followed by the Livestock density Index (LSI_m; R^2=

0.23) and the density of tree lines and hedgerows ($DT_{m;}$ R^2=0.18). Variation observed for indicators revealed distinct patterns across clusters (a), (b) and (c), cf. Table 4. Overall, cluster (a) showed the highest values for the share of intensive crops ($P.ICrops_m$: 0.69±0.15) and lowest values for crop diversity (SEI_m: 0.39±0.057). Conversely, cluster (b) was characterized by the lowest value for the share of intensive crops ($P.ICrops_m$: 0.30±0.11) while showing the highest values for crop diversity (SEI_m: 0.50±0.056) and density of linear elements (DT_m: 5.59±2.71). As for the livestock density index (LSI_m) average values lower than 0.50 LSU per ha/UAA were observed within clusters. Considering both LSI_m variation and discrimination ability (cf. R^2 value, Table 4), the share of intensive crops was considered most important regarding the intensity of farming practices across clusters (a), (b) and (c). Thus, differences observed across clusters supported their classification according to HNVf types. Cluster (a) was considered to include farmlands under intensive farming practices and therefore classified as non-HNVf. Due to lower shares of intensive crops and higher crop diversity and density of linear elements, cluster (b) was considered most likely to support both HNVf types 1 and 2. Finally, cluster (c) was classified as potentially supporting HNVf type 2.

#Table 4 and Fig. 4 approximately here#

3.3. Fine-scale assessment of High Nature Value farmlands in Lower Saxony

The results of the fine-scale assessment of HNVf (Step 3b) are presented in Table 5. Overall, farmlands considered suitable for a fine-scale assessment of HNVf (including clusters (b) and (c); Step 3a, cf. Fig 4), totaled 429,471.16 ha of UAA (86,253 physical blocks).

#Table 5 approximately here#

From the area identified as potentially supporting HNVf1 and 2 (cluster (b), Fig. 4), 5,024 physical blocks showed the highest values for both grasslands ($P.G_{pb} \geq 83.41\%$) and grasslands under agri-environment schemes (cf. $P.GAES_{pb} \geq 9.93$; cf. Table 5), and were thus considered likely to correspond to HNVf1. In addition, 9,884 physical blocks showed the highest values for crop diversity (cf. Table 5, $SEI_{pb} \geq 0.58$) while having the lowest shares of intensive crops ($P.ICrops_{pb} \leq 0.24$; cf. Table 5)HNVf2 potential area (cf. cluster (c) Fig. 4) included 28,445 physical blocks, corresponding to 129,435.48 ha of UAA. Analysis of variation within indicators at the physical block level (cf. Table 5) resulted in a final HNVf2 area including ca. 19 % of total physical blocks (5542, corresponding to 17,841.68 ha of UAA). Those physical blocks showed the highest values of crop diversity, reflected as $SEI_{pb} \geq 0.49$, and the lowest share of intensive crops $P.ICrops_{pb} < 0.88$ (cf. Table 5).

Spatially-explicit representation of HNVf1 and HNVf2 fine-scale assessment (Step 3b) is presented in Fig. 5.

#Fig. 5 approximately here#

4. Discussion

4.1. IACS data and the assessment of HNVf in Lower Saxony

Overall, spatially explicit indicators derived from IACS allowed the assessment of HNVf in Lower Saxony, following the methodological approach recently described by (Lomba *et al.*, 2015). Indicators reflecting landscape structure and composition, extensive farming practices, and crop diversity used within each step of the described approach (cf. Table 1), were considered to be the best trade-off between IACS thematic, spatial and temporal resolution, and available information regarding farming systems and their variation across the study-area. As the definition of hard thresholds for indicators for HNVf assessment is far from being consensual, our analysis was assumed to be region (or administrative unit) specific (e.g. see Boyle *et al.*, 2015). Whilst such assumption may hamper our ability to cope with HNVf assessment when continuous regions are assessed individually, it may also be an added-value. In fact, such an approach has higher potential to be implemented on broader scales, thus allowing the validation of regional assessments, and the harmonization of criteria at the national level. Moreover, in order to provide and target cost-effective support under the CAP, detailed knowledge on the distribution and extent of HNVf is needed (Keenleyside *et al.*, 2014). In this regard, our results may contribute to improved targeting, monitoring and evaluating the impact of CAP support for HNVf.

The link between IACS and the Land Parcel Identification Systems (LPIS), which covers most agricultural areas, allowed HNVf extent to be ascertained in relation to the Utilized Agricultural Area, and thus comply with EU standards for reporting HNV indicators (EENRD, 2009; Lomba *et al.*, 2015). Due to its high spatial and thematic high-resolution (Nitsch *et al.*, 2012; Strohbach *et al.*, 2015), IACS data allowed the assessment of HNVf at two different spatial scales, the municipality, coincident with the local decision level (LAU 2), and the physical block, corresponding to a fine-scale level (cf. Fig. 2). In addition, the approach adopted in this study also allowed discrimination between HNV farmlands with a high proportion of agriculture dependent habitats (HNVf 1; Lomba *et al.*, 2014) and mosaics of semi-natural and small-scale landscape features (HNVf2; Lomba *et al.*, 2014).

In Lower Saxony, as across the majority of Germany, most agricultural landscapes are currently under intensive farming practices (Nitsch *et al.*, 2012; Oppermann *et al.*, 2012; Klimek *et al.*, 2014), which makes the assessment of High Nature Value farmlands and targeting of CAP support measures quite a challenge. Whilst extensive farming practices are not widely adopted across Lower Saxony, some landscapes have been described as farmlands with high nature value and thus under HNV farming systems, particularly semi-natural grasslands (Oppermann *et al.*, 2012).

Indicators expressing the extensive character of farming practices, including the livestock density index and the share of intensive crops, were analyzed to achieve deeper insights on differences between farming systems across the study area. Spatial-statistics analysis resulted in the delineation of two farmland-dominated regions, coincident with western and eastern areas of Lower Saxony (clusters (A) and (B); cf. Fig. 3). Importantly, the livestock density index had the best discriminating ability across Lower Saxony (cf. Table 3). As a result, the Western part of Lower Saxony (cluster (A), Fig. 3), where farmland-dominated municipalities were generally intensively managed in terms of livestock density, was considered as non-HNV farmland. This corresponds to recent studies that have demonstrated that some districts in western Lower Saxony (e.g. ‘Vechta’ and ‘Cloppenburg’) are characterized by the highest densities of livestock in Germany and Europe, respectively (Deblitz *et al.*, 2008; Neumann *et al.*, 2009). Smit *et al.* (2008) further highlighted that estimated grassland productivity (dt ha^{-1}) and milk production per ha UAA is comparatively high throughout the northwestern part of Lower Saxony. Moreover, it has been shown that the western part of Lower Saxony is characterized by widespread and intensive cultivation of maize for use as fodder or corn and for biogas production (Nitsch *et al.*, 2012; Steinmann and Dobers, 2013). The eastern region of Lower Saxony was found to exhibit lower livestock density values (cluster (B), Fig. 3; cf. Table 3), and was thus considered more likely to support farmlands with high nature value (cf. Table 3). As a result, only farmland-dominated municipalities within the Eastern region of Lower were considered for detailed analysis.

Subsequent analysis was built on three sets of indicators, expressing the landscape structure and composition, the extensive character of farming practices and crop diversity. Spatial-statistics analysis performed in Step 3a allowed the selection of municipalities under intensive farming systems, reflected as higher shares for intensively managed crops and low crop diversity (cf. Table 4; cluster (a) Fig. 4), thus assumed as non-HNVf (cf. Fig. 4). Cluster (a) (cf. Fig. 4), coincident with the 'Braunschweig-Hildesheimer Lößbörde' area is, in fact, characterized by fertile loess soils and large-scale production of intensive crops such as sugar beet and winter wheat. As for clusters (b) and (c) (cf. Fig. 4), variation of extensive farming practices, crop diversity indicators and landscape elements sets of indicators (cf. Table 4) supported their classification as farmlands with potential to support both HNVf1 and 2 (North region, Eastern Lower Saxony) or only HNVf2 (South region, Eastern Lower Saxony), respectively. Cluster (b) was found to be under more extensive farming practices (expressed as lower values for both the share of intensively managed crops and livestock density index; cf. Table 4), while showing higher crop diversity and density of linear elements. Accordingly, cluster (b) was considered to be a mosaic of semi-natural vegetation (HNVf1) and low intensity cultivated land intermingled with small-scale landscape elements (HNVf2) (Boyle *et al.*, 2015; Lomba *et al.*, 2015)

A fine-scale analysis, implemented at the physical block level (cf. Table 5 and Fig. 5), allowed the refinement of the initial HNVf1 and HNVf2 assessments. Building upon a thorough analysis of variation of all sets of indicators at the scale of the physical-block (high spatial resolution), such refinement contributed to a more detailed delineation of farmlands with the potential for high nature value in the study area.

By definition, HNVf1 owe their nature value to the presence of semi-natural agriculture-related habitats (e.g. Andersen *et al.*, 2003 and Lomba *et al.*, 2014). It has been demonstrated that the area covered by semi-natural habitats at the farm or landscape scale could be used as an effective proxy for farmland biodiversity (e.g. Boyle *et al.*, 2015, but see also Billeter *et al.*, 2008). Even though essential e.g. for HNVf1 assessment, comprehensive spatial-explicit surveys of semi-natural grasslands are seldom available at the regional or national scales (Veen *et al.*, 2009). Here, this limitation was mitigated by deriving the share of the physical block covered by permanent grasslands and the share of grasslands under agri-environment scheme management contracts from IACS data, and considering both indicators as proxies for the occurrence of semi-natural grasslands (cf. Table 1 and Table 5; Boyle *et al.*, 2015). In fact, while permanent grasslands are not included within crop rotations for more than five consecutive years (contrary to temporary grasslands, (Huyghe *et al.*, 2014), permanent grasslands under agri-environment scheme management contracts are further characterized by restrictions on farming intensity such as limited stocking rates, restricted use of fertilizers and chemical pesticides, and can therefore be assumed to be more extensively managed (Boyle *et al.*, 2015). Incorporating information on the occurrence of habitats and species known to be associated with HNV farmlands would constitute an important contribution to our results, by providing data for testing the sensitivity of the methodological approach (Lomba *et al.*, 2015) and validation of results (Doxa *et al.*, 2010).

Overall, our results indicated that only 3% of the UAA of Lower Saxony constituted High Nature Value farmlands. Also, whilst ca.1% of the total UAA of Lower Saxony corresponded to semi-natural grasslands under extensive farming practices (HNVf1; cf. section 3.3 and Table 5), more than 70% of all HNV farmlands were found to be HNVf type 2. Even though HNVf types 1 and 2 were considered to co-occur, spatial patterns pinpointed the floodplains of the Elbe River as one hot-spot for HNVf1 (cf. Fig. 5). As described by (Ludewig *et al.*, 2014), these species-rich floodplain meadows are among the most threatened plant communities in Europe. Moreover, our delineation of areas under HNVf is generally in agreement with those of Oppermann *et al.*, 2012. Discrimination of the nature value farmlands as HNVf1 and HNVf2, according to *Andersen et al.*, 2003, may constitute in the future a tool for the optimization of monitoring programs and for establishing priority areas to be supported under agri-environmental schemes.

4.2. IACS data and the assessment of HNVf across Europe

Our study demonstrated the potential of IACS as a tool for HNVf assessment across the EU countryside. IACS was used as data source to derive sets of spatially-explicit indicators characterizing landscape elements, extensive practices and crop diversity.

However, even though IACS has high potential for being used for HNVf assessment across EU, some challenges concerning the use of IACS remain to be addressed (e.g. see Lomba *et al.*, 2014; Strohbach *et al.*, 2015).

Due to its thematic resolution, IACS data allows for the discrimination between crop types and some agriculture-related habitats such as permanent and temporary grasslands, which is an added-value when compared with broad-scale land-cover and/or land-use data such as Corine Land Cover maps. However, in some cases, habitats likely to be HNVf type 1 may not be accounted for as eligible agricultural area within IACS, due to CAP-related subsidy regulations, namely grasslands constituting common grazing land or woody pastures (Jakobsson and Lindborg, 2015). Overcoming such limitations, incorporating semi-natural habitats that constitute HNVf1, would most likely require ancillary data, such as vegetation/habitat maps or ground-based surveys. However, even though spatially-explicit data on vegetation and ecosystem types, and vegetation databases are available for some European Member States (Veen *et al.*, 2009; Chytrý, 2015), their potential to be used to complement IACS data will depend, to a large extent, on their thematic, spatial and temporal resolution, and thus will have to be assessed whenever its required.

Currently, efforts are been made towards the simplification of EU agricultural control procedures, including the amount of information that farmers and land managers are asked to report each year. Even though such a review of IACS is regarded as being essential by the EU and Member States, we argue that the benefits to the wider society from the use of such data could far outweigh the requirements being put on the beneficiaries of CAP payments. In addition, a thorough analysis of the full potential to use pre-existing IACS spatial and temporal data for such wider purposes than originally intended may provide key information and evidence to the ongoing IACS review. Nevertheless, the potential applicability of IACS as data source for HNVf assessment would be enhanced if other information e.g. reflecting fertilizer and pesticide inputs would be recorded and incorporated. Such information would be essential to further inform on the intensity of farming practices underlying farming systems, and thus enable a more precise identification of extensively managed farmlands likely to be HNVf. While requesting more information under IACS surveys may imply more short-time costs, long-term trade-offs between costs and benefits should be considered e.g. IACS data usage for improved targeting, monitoring and evaluating of agri-environment schemes.

HNVf assessment using IACS time-series data for other territories within the EU would allow progress on the evaluation of farmlands with high nature value in space and time. Such progress would benefit from research focusing specifically the evaluation and eventually the re-definition of spatially-explicit indicators that could support the selection of a set of informative and cost-effective indicators for that purpose. IACS data collection does, however, differ between Member States in terms of spatial and thematic resolution. It is therefore of utmost importance to test its use in other social-ecological contexts, to evaluate how widespread such data could be used across Europe. Extending HNVf assessment using IACS data to other EU Member States would also allow testing the ability of the approach to cope with the variation of HNV landscapes across the EU. At the same time, it would allow the assessment of issues relating to differences in data quality and compatibility between and within Member States, that may hamper our ability to implement similar approaches across EU.

5. Conclusions

Our results highlight the potential of IACS as spatially and thematic high-resolution data source for assessing and monitoring the extent of High Nature Value farmlands in the EU. Even though trade-offs between thematic and spatial resolution of available

IACS data need to be weighted for each targeted area, the conceptual and methodological approach is, from our point of view, flexible enough to allow an effective assessment of HNVf in space and time across the EU countryside.

Overall, making use of IACS data in such a way could provide a stepping-stone towards achieving a more effective balance between the management and control of CAP support payments and the growing societal demands related to the maintenance and enhancement of farmland biodiversity and ecosystem services.

Acknowledgements

A.L. is supported by the Portuguese Science and Technology Foundation (FCT) through Post-Doctoral Grant SFRH/BPD/ 80747/2011. D.M. input to this manuscript was partially funded by the Scottish Government Rural Affairs & Environment Portfolio Strategic Research Programme 2011-2016, Theme 3: Land-use.

The authors would like to thank the Lower Saxony Ministry of Food, Agriculture, Consumer Protection for providing access to the data from the Integrated Administration and Control System (IACS).

5. References

Andersen, E., Baldock, D., Bennett, H., Beaufoy, G., Bignal, E., Bouwer, F., Elbersen, B., Eiden, G., Giodeschalk, F., Jones, G., McCracken, D., Nieuwenhuizen, W., Eupen, M.v., Hennekes, S., Zervas, G., 2003. Developing a high nature value farming area indicator: final report. p. 75.

Aviron, S., Nitsch, H., Jeanneret, P., Buholzer, S., Luka, H., Pfiffner, L., Pozzi, S., Schüpbach, B., Walter, T., Herzog, F., 2009. Ecological cross compliance promotes farmland biodiversity in Switzerland. Frontiers in Ecology and the Environment 7, 247-252.

Balmford, A., Green, R., Phalan, B., 2012. What conservationists need to know about farming. Proceedings of the Royal Society B 279, 2714-2724.

Bartel, A., Süßenbacher, E., Sedy, K., 2011. High Nature Value Farmland" für Österreich: Weiterentwicklung des Indikators, http://www.umweltbundesamt.at/fileadmin/site/publikationen/REP0348.pdf (last accessed 06.09.15).

Baudron, F., Giller, K.E., 2014. Agriculture and nature: Trouble and strife? Biological Conservation 170, 232-245.

Beaufoy, G., Baldock, D., Clarke, J., 1994. The Nature of Farming - Low Intensity Farming Systems in Nine European Countries. IEEP, London. p. 68.

Beilin, R., Lindborg, R., Stenseke, M., Pereira, H.M., Llausàs, A., Slätmo, E., Cerqueira, Y., Navarro, L., Rodrigues, P., Reichelt, N., Munro, N., Queiroz, C., 2014. Analysing how drivers of agricultural land abandonment affect biodiversity and cultural landscapes using case studies from Scandinavia, Iberia and Oceania. Land Use Policy 36, 60-72.

Bignal, E.M., McCracken, D.I., 1996. Low-intensity farming systems in the conservation of the countryside. Journal of Applied Ecology 33, 413-424.

Billeter, R., Liira, J., Bailey, D., Bugter, R., Arens, P., Augenstein, I., Aviron, S., Baudry, J., Bukacek, R., Burel, F., Cerny, M., De Blust, G., De Cock, R., Diekotter, T., Dietz, H., Dirksen, J., Dormann, C., Durka, W., Frenzel, M., Hamersky, R., Hendrickx, F., Herzog, F., Klotz, S., Koolstra, B., Lausch, A., Le Coeur, D., Maelfait, J.P., Opdam, P., Roubalova, M., Schermann, A., Schermann, N., Schmidt, T., Schweiger, O., Smulders, M.J.M., Speelmans, M., Simova, P., Verboom, J., van Wingerden, W.K.R.E., Zobel, M., 2008. Indicators for biodiversity in agricultural landscapes: a pan-European study. Journal of Applied Ecology 45, 141-150.

Boyle, P., Hayes, M., Gormally, M., Sullivan, C., Moran, J., 2015. Development of a nature value index for pastoral farmland—A rapid farm-level assessment. Ecological Indicators 56, 31-40.

Chytrý, M., Dražil, T., Hájek, M., Kalníková, V., Preislerová, Z., Šibík, J., Ujházy, K., Axmanová, I., Bernátová, D., Blanár, D., Dančák, M., Dřevojan, P., Fajmon, K., Galvánek, D., Hájková, P., Herben, T., Hrivnák, R., Janeček, S., Janišová, M., Jiráská, S., Kliment, J., Kochjarová, J., Lepš, J., Leskovjanská, A., Merunková, K., Mládek, J., Slezák, M., Šeffer, J., Šefferová, V., Škodová, I., Uhlířová, J., Ujházyová, M., Vymazalová, M., 2015. The most species-rich plant communities in the Czech Republic and Slovakia (with new world records). Preslia 87, 217-278.

Deblitz, C., Brömmer, J., brüggemann, D., 2008. Beef production in Germany - production systems and their spatial distribution. vTI Agriculture and Forestry Research 58, 29-44.

Dormann, C.F., Elith, J., Bacher, S., Buchmann, C., Carl, G., Carré, G., Marquéz, J.R.G., Gruber, B., Lafourcade, B., Leitão, P.J., Münkemüller, T., McClean, C., Osborne, P.E., Reineking, B., Schröder, B., Skidmore, A.K., Zurell, D., Lautenbach, S., 2013. Collinearity: a review of methods to deal with it and a simulation study evaluating their performance. Ecography 36, 27-46.

Doxa, A., Bas, Y., Paracchini, M.L., Pointereau, P., Terres, J.-M., Jiguet, F., 2010. Low-intensity agriculture increases farmland bird abundances in France. Journal of Applied Ecology 47, 1348-1356.

EC, 1996. Council Regulation (EC) amending Regulation (EEC) No 3508/92 establishing an integrated administrative and control system for certain Community aid schemes ('integrated system'). COM (96) 174 final. Brussels, p. 48.

EC, 2006. Rural Development 2007-2013 Handbook on Common Monitoring and Evaluation Framework; Guidance document. Brussels: DG for Agriculture and Rural Development. p. 15.

EC, 2015. Report from the Commission to the European Parliament and the Council. The mid-term review of the Eu Biodiversity Strategy to 2020. p. 19.

EEA, 2015. The European environment — state and outlook 2015: synthesis report, European Environment Agency, Copenhagen. p. 212.

EEC, 1992. COUNCIL REGULATION (EEC) No 3508/92 of 27 November 1992 establishing an integrated administration and contrbl system for certain Community aid schemes. p. 5.

EENRD, 2009. Guidance Document-The Application of the High Nature Value Impact Indicator Programming Period 2007-2013. In: Communities, E. (Ed.). European Evaluation Network for Rural Development, Brussels, p. 45.

Egan, J.F., Mortensen, D.A., 2012. A comparison of land-sharing and land-sparing strategies for plant richness conservation in agricultural landscapes. Ecological Applications 22, 459-471.

ESRI, 1999-2015. ArcMap 10.3.1. Environmental Systems Research Institute Inc.

Halada, L., Evans, D., Romão, C., Petersen, J.-E., 2011. Which habitats of European importance depend on agricultural practices? Biodiversity and Conservation 20, 2365-2378.

Huyghe, C., De Vliegher, A., van Gils, B., Peeters, A., 2014. Grasslands and herbivore production in Europe and effects of common policies. In: Huyghe, C., De Vliegher, A., van Gils, B., Peeters, A. (Eds.). Quae, p. 320.

Jakobsson, S., Lindborg, R., 2015. Governing nature by numbers — EU subsidy regulations do not capture the unique values of woody pastures. Biological Conservation 191, 1-9.

Keenleyside, C., Beaufoy, G., Tucker, G., Jones, G., 2014. High Nature Value farming throughout EU-27 and its financial support under the CAP. Report Prepared for DG Environment, Contract No ENV B.1/ETU/2012/0035, Institute for European Environmental Policy, London. p. 385.

Klimek, S., Lohss, G., Gabriel, D., 2014. Modelling the spatial distribution of species-rich farmland to identify priority areas for conservation actions. Biological Conservation 174, 65-74.

Klimek, S., Richter gen. Kemmermann, A., Hofmann, M., Isselstein, J., 2007. Plant species richness and composition in managed grasslands: The relative importance of field management and environmental factors. Biological Conservation 134, 559-570.

Lomba, A., Alves, P., Jongman, R.H.G., McCracken, D.I., 2015. Reconciling nature conservation and traditional farming practices: a spatially explicit framework to assess the extent of High Nature Value farmlands in the European countryside. Ecology and Evolution 5, 1031-1044.

Lomba, A., Guerra, C., Alonso, J., Honrado, J.P., Jongman, R., McCracken, D., 2014. Mapping and monitoring High Nature Value farmlands: Challenges in European landscapes. Journal of Environmental Management 143, 140-150.

Ludewig, K., Korell, L., Löffler, F., Scholz, M., Mosner, E., Jensen, K., 2014. Vegetation patterns of floodplain meadows along the climatic gradient at the Middle Elbe River. Flora - Morphology, Distribution, Functional Ecology of Plants 209, 446-455.

MacDonald, D., Crabtree, J.R., Wiesinger, G., Dax, T., Stamou, N., Fleury, P., Gutierrez Lazpita, J., Gibon, A., 2000. Agricultural abandonment in mountain areas of Europe: Environmental consequences and policy response. Journal of Environmental Management 59, 47-69.

Millennium Ecosystem Assessment, 2005. Ecosystems and Human Well-being: Biodiversity Synthesis. In: Institute, W.R. (Ed.). World Resources Institute, Washington, DC. p. 100.

Neumann, K., Elbersen, B.S., Verburg, P.H., Staritsky, I., Pérez-Soba, M., Vries, W., Rienks, W.A., 2009. Modelling the spatial distribution of livestock in Europe. Landscape Ecology 24, 1207-1222.

Nitsch, H., Osterburg, B., Roggendorf, W., Laggner, B., 2012. Cross compliance and the protection of grassland - Illustrative analyses of land use transitions between permanent grassland and arable land in German regions. Land Use Policy 29, 440-448.

Oppermann, R., Beaufoy, G., Jones, G., 2012. (eds). High Nature Value farming in Europe. 35 European countries: experiences and perspectives. Verlag Regionalkultur, Ubstadt-Weiher, Germany. p. 544.

Paracchini, M.L., Petersen, J.-E., Hoogeveen, Y., Bamps, C., Burfield, I., Van Swaay, C., 2008. High Nature Value Farmland in Europe - An estimate of the distribution patterns on the basis of land cover and biodiversity data. In: Communitites, O.f.O.P.o.t.E. (Ed.), JRC Scientific and Technical Reports. Joint Research Centre - Institute for Environment and Sustainability, Luxembourg. p. 87.

Peppiette, Z.E.N., 2011. The challenge of monitoring environmental priorities: the example of HNV farmland. Paper prepared for the 122nd EAAE seminar Evidence-based agricultural and rural policy making: Methodological and empirical challenges of policy evaluation. Ancona, 2011.

Plieninger, T., Bieling, C., 2012. Resilience and the Cultural Landscape: Understanding and Managing Change in Human-Shaped Environments. Cambridge University Press.p. 366.

Plieninger, T., Bieling, C., 2013. Resilience-Based Perspectives to Guiding High-Nature-Value Farmland through Socioeconomic Change. Ecology and Society 18.

Power, A.G., 2010. Ecosystem services and agriculture: tradeoffs and synergies. Philosophical Transactions of the Royal Society B: Biological Sciences 365, 2959-2971.

Renwick, A., Jansson, T., Verburg, P.H., Revoredo-Giha, C., Britz, W., Gocht, A., McCracken, D., 2013. Policy reform and agricultural land abandonment in the EU. Land Use Policy 30, 446-457.

Ribeiro, P.F., Santos, J.L., Bugalho, M.N., Santana, J., Reino, L., Beja, P., Moreira, F., 2014. Modelling farming system dynamics in High Nature Value Farmland under policy change. Agriculture, Ecosystems & Environment 183, 138-144.

Sagris, V., Devos, W., 2009. Core conceptual model for Land Parcel Identification System (LCM), GeoCAP version 1.1. JRC Scientific and Technical Reports. 53 pp.

Scottish Government 2011. Developing High Nature Value Farming and Forestry indicators for the Scotland Rural Development Programme: Summary report of the

Technical Working Group on High Nature Value Farming and Forestry Indicators. Web only publication: http://www.scotland.gov.uk/Resource/Doc/355629/0120133.pdf [Accessed 4th march 2016]

Shackelford, G.E., Steward, P.R., German, R.N., Sait, S.M., Benton, T.G., 2015. Conservation planning in agricultural landscapes: hotspots of conflict between agriculture and nature. Diversity and Distributions 21, 357-367.

Smit, H.J., Metzger, M.J., Ewert, F., 2008. Spatial distribution of grassland productivity and land use in Europe. Agricultural Systems 98, 208-219.

Statsoft, I., 2013. STATISTICA (data analysis software system), version 12.0. www.statsoft.com.

Steinmann, H.-H., Dobers, E.S., 2013. Spatio-temporal analysis of crop rotations and crop sequence patterns in Northern Germany: potential implications on plant health and crop protection. Journal of Plant Diseases and Protection 120, 85-94.

Stoate, C., Báldi, A., Beja, P., Boatman, N.D., Herzon, I., van Doorn, A., de Snoo, G.R., Rakosy, L., Ramwell, C., 2009. Ecological impacts of early 21st century agricultural change in Europe - A review. Journal of Environmental Management 91, 22-46.

Strohbach, M.W., Kohler, M.L., Dauber, J., Klimek, S., 2015. High Nature Value farming: From indication to conservation. Ecological Indicators 57, 557-563.

Swinton, S.M., Lupi, F., Robertson, G.P., Hamilton, S.K., 2007. Ecosystem services and agriculture: Cultivating agricultural ecosystems for diverse benefits. Ecological Economics 64, 245-252.

van Vliet, J., de Groot, H.L.F., Rietveld, P., Verburg, P.H., 2015. Manifestations and underlying drivers of agricultural land use change in Europe. Landscape and Urban Planning 133, 24-36.

Veen, P., Jefferson, R., de Smidt, J., van der Straaten, J., 2009. Grasslands in Europe of high nature value. KNNV Pub. p. 319.

Wade, M.R., Gurr, G.M., Wratten, S.D., 2008. Ecological restoration of farmland: progress and prospects. Philosophical Transactions of the Royal Society B: Biological Sciences 363, 831-847.

Title: Making the best of both worlds: can high-resolution agricultural administrative data support the assessment of High Nature Value farmlands across Europe?

Figures and tables

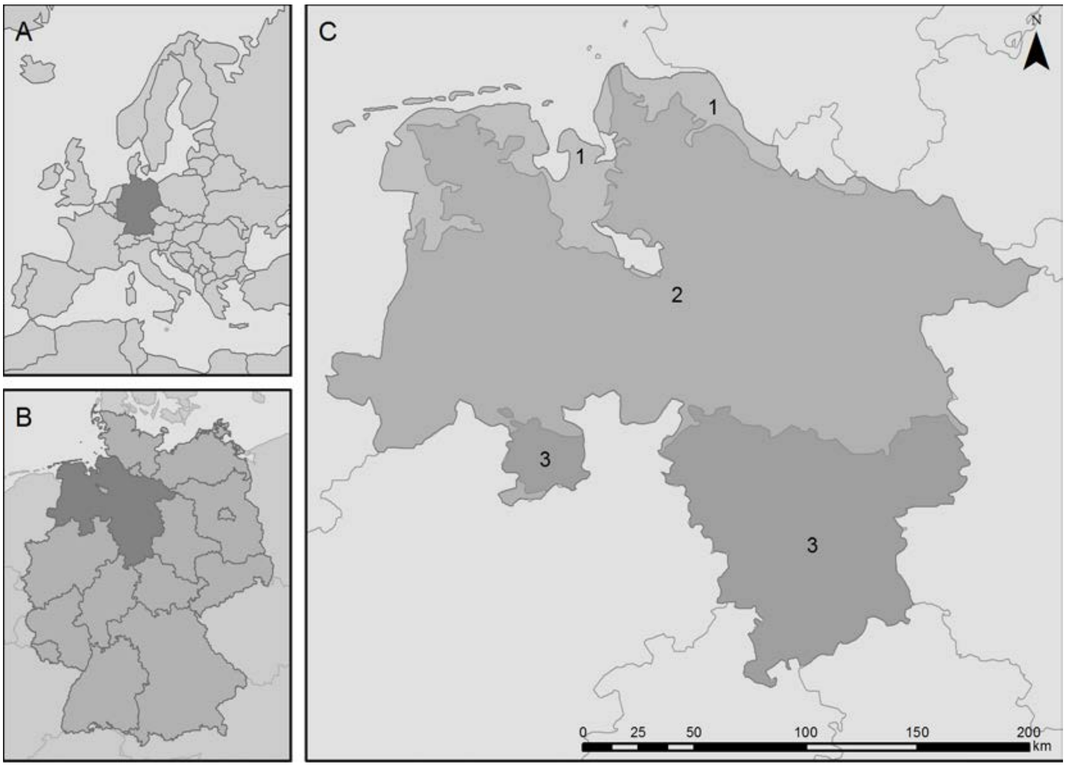

Fig. 1. The geographic location of the study area, the federal state of Lower Saxony, within Europe (A) and Germany (B), and the three major biogeographical regions dividing the study area (C): coastal areas (1), the lowlands (2) and the uplands (3).

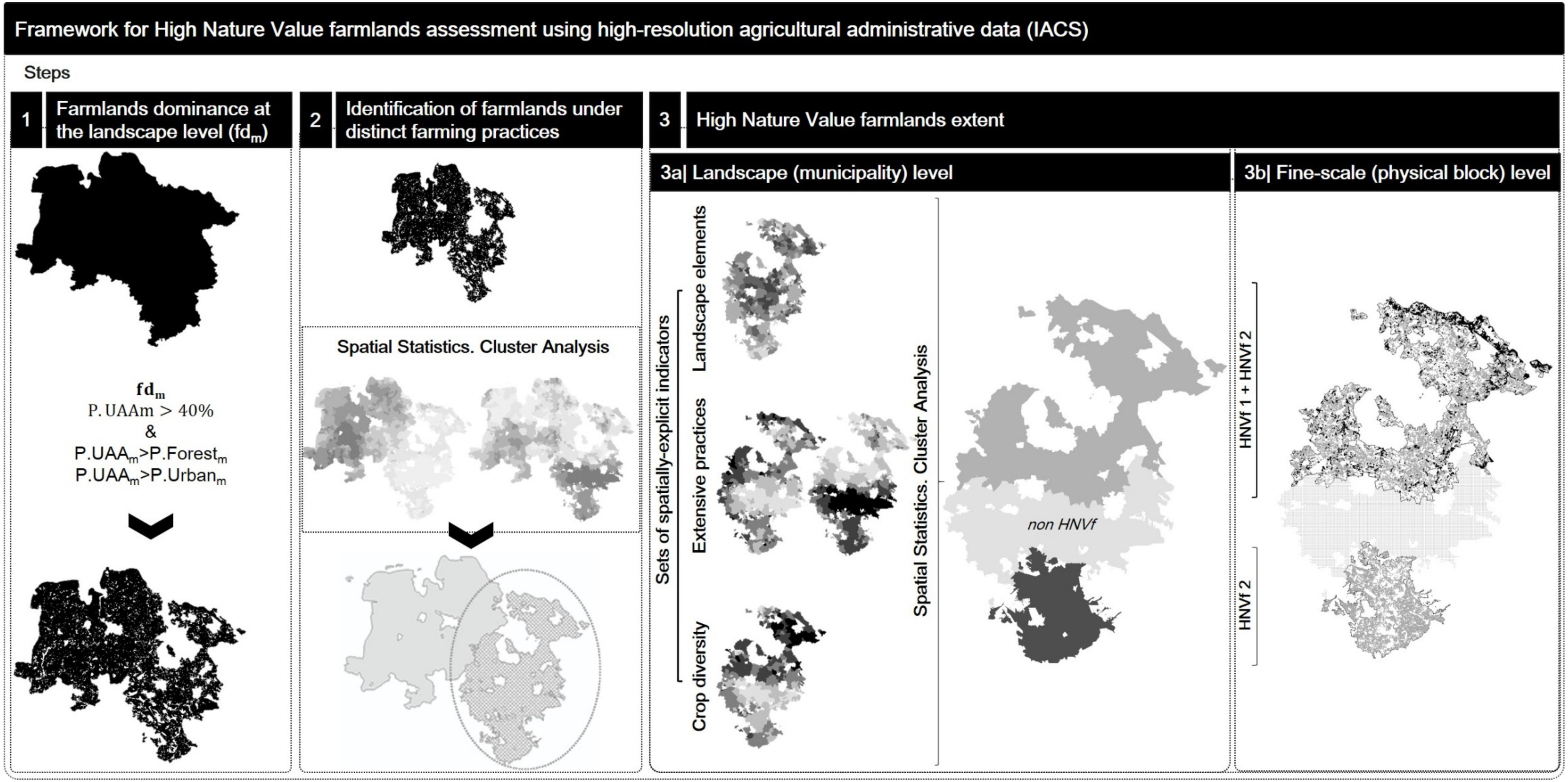

Fig. 2. Framework implemented to assess the extent of High Nature Value farmlands (HNVf) in Lower Saxony using high-resolution administrative agricultural data. Overall, the presented framework consists on a three-step, sequential, multi-criteria analysis of spatially-explicit

indicators. In Step 1, indicators informing on the composition of the landscape, including the percentage of utilized agricultural ($P.UAA_m$), forest ($P.Forest_m$), and urban areas ($P.Urban_m$), were used to highlight municipalities where farmlands were dominant at the landscape level (fd_m). Farmland dominance was defined considering a minimum threshold value of 40% of $P.UAA_m$, and the prevalence of higher values for the percentage cover of Utilized Agricultura Area ($P.UAA_m$) in relation to forest ($P.Forest_m$) and urban areas ($P.Urban_m$). Step 2, implemented on farmland-dominated municipalities selected in Step 1, consisted of a spatially-explicit analysis of patterns of indicators expressing the intensity of farming pactices aiming to discriminate areas under distinct farming practices. By discriminating such areas, we aimed to focus on extensively managed farmlands, as those more likely to support farmlands with high nature value. In Step 3, areas of HNVf types 1 and 2 were , by first implementing a landscape-level analysis of spatially-explicit patterns for indicators reflecting extensive farming practices, landscape elements and crop diversity (Step 3a) and, combining outcomes from such analysis with a fine-scale analysis, built on high-resolution data at the physical block level, in Step 3b.

Table 1. Sets of spatially-explicit indicators used to assess the extent of High Nature Value farmlands in Lower Saxony, Germany. Steps of analysis: Step 1 consisted on the definition of farmlands dominance at the landscape level (municipality); Step 2 highlighted areas under farming practices more likely to support farmlands with high nature value; and, Step 3 targeted areas of HNVf types 1 and 2 by first implementing a landscape-level detailed analysis (Step 3a), combined with a fine-scale analysis built on high-resolution data at the physical block level (Step 3b). (%), percentage; (n.a.), not applicable; (ha), hectares; HNVf1, High Nature Value farmlands type 1; HNVf2, High Nature Value farmlands type 2.

Designation	Code(s) and units	Rationale	Source and determination	Step of analysis	HNVf types
Landscape elements					
Farmlands dominance in the landscape	$P.UAA_m$ (%)	Areas where the percentage (%) cover of farmlands ($P.UAA_m$) is dominant in relation to forests ($P.Forest_m$) and urban areas ($P.Urban_m$), at the municipality level. Values were calculated from the area covered by each class (farmland, forest and urban) in relation to the total municipality area, and are thus expressed as the percentage. A threshold value of 40% $P.UAA_m$ was considered to define farmland dominance at the municipality level, following the rule of thumb proposed by	IACS and associated LPIS	Step 1	Types 1 and 2
	$P.Forest_m$ (%)		Basis-DLM Forest, including closed deciduous and coniferous forests classes.		
	$P.Urban_m$ (%)		Basis-DLM Urban and built-up areas covered by buildings, streets and other urban		

		Lomba *et al (2015)*.	land-uses.		
Density of tree lines and hedgerows	DT_m (m/ha)	Density of tree lines and hedgerows within each municipality.	Basis-DLM Areas covered by linear elements, including rows of trees, hedges and hedge-banks.	Step 3a	Type 2
Share of grasslands in each physical block	$P.G_{pb}$ (%)	Determined as the share of the physical block covered by grasslands, highlights areas predominantly covered by grasslands.	IACS	Step 3b	Type 1
Extensive practices					
Livestock Density Index	LSI_m (total LSU per ha/UAA)	Indicator expressing the pressure of livestock on the environment, measured as livestock units (LSU) per hectare of UAA	IACS	Step 2 Step 3a	Types 1 and 2

		(LSU/ha) at the municipality level. Lowest values of LSI_m are usually observed in landscapes were semi-natural forage (i.e. permanent grasslands) predominates.			
Share of intensive crops	P.ICrops$_m$ (%)	Determined as the share of UAA covered by intensive types of crops (winter wheat, sugar beet, maize and oilseed rape), highlights municipalities under intensive farming practices.	IACS	Step 2	Types 1 and 2
	P.ICrops$_{pb}$ (%)	Determined as the share of UAA covered by intensive crops (winter wheat, sugar beet, maize and oilseed rape) at the level of the physical block.	IACS	Step 3b	Type 2

Share of grasslands under agri-environment schemes in each physical block	$P.GAES_{pb}$ (%)	Determined as the share of the physical block covered by permanent grasslands under agri-environment scheme management contracts.	IACS	Step 3b	Type 1
Crop diversity					
Cropping patterns	SEI_m (n.a.)	Cropping patterns expressed as the Shannon Evenness Index. The index accounts for the diversity of crops and the evenness of their distribution and was calculated at the municipality level using the shares of crops registered in the IACS database. Varies between 0 and 1.	IACS	Step 3a	Type 2
	SEI_{pb} (n.a.)	Cropping patterns expressed as the Shannon Evenness Index on farm level, averaged at the physical block level.	IACS	Step 3b	Type 2

Table 2. Variation of spatially-explicit sets of indicators (landscape elements, extensive practices and crop diversity) across municipalities dominated by farmlands in Lower Saxony. (%) stands for percentage; n.a., not applicable. Mean, minimum (Min), maximum (Max) and standard deviation (SD) values are presented.

Sets of indicators	**Code and units**	**Mean**	**SD**	**Min**	**Max**
Landscape elements	DT_m (ha)	4.14	3.24	0.00	23.10
Extensive practices	LSI_m (LSU per ha/UAA)	0.99	0.69	0.00	3.20
	$P.ICrops_m$ (%)	0.39	0.20	0.00	0.99
Crop diversity	SEI_m *(n.a.)*	0.38	0.10	0.04	0.63

Table 3. Clusters resulting from the spatially-explicit analysis of indicators expressing the extensive character of farming practices across farmland dominated municipalities in Lower Saxony. *n*, stands for the number of municipalities. Mean, minimum (Min), maximum (Max) and standard deviation (SD) values are presented. Share values depict the ratio between the range of values observed within groups (A, B) and the full range of values observed for each indicator.

Cluster	***n***	**Code and units**	**Mean**	**SD**	**Min**	**Max**	**Share (%)**
A	496	LSI_m (LSU per ha/UAA)	1.50	0.48	0.080	3.20	0.98
		$P.ICrops_m$ (%)	0.31	0.13	0.01	0.66	0.66
B	391	LSI_m (LSU per ha/UAA)	0.37	0.24	0.00	1.18	0.37
		$P.ICrops_m$ (%)	0.50	0.22	0.050	0.99	0.96

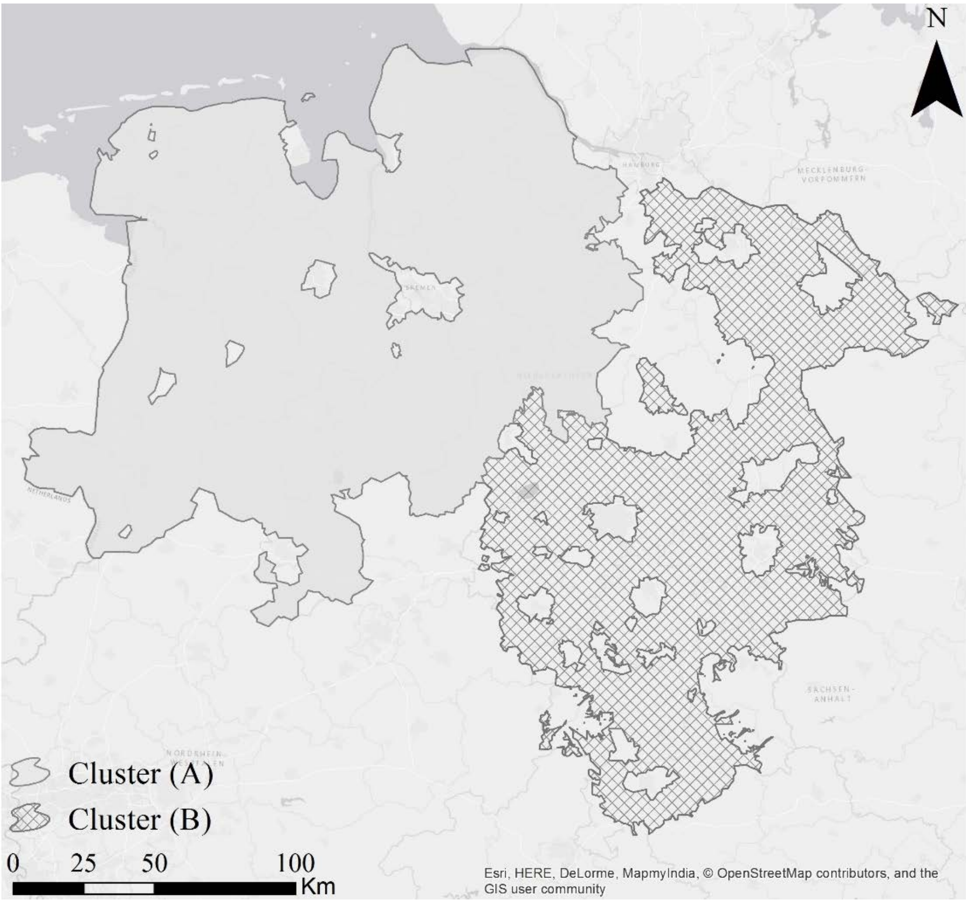

Fig. 3. Outcomes of grouping analysis implemented on the extensive farming practices set of indicators. Groups (A and B) resulted from the cluster analysis of patterns for both the livestock density index and the share of intensive crops across farmland-dominated municipalities across Lower Saxony. Clusters reflected either high values of LSI_m and moderate levels of $P.ICrops_m$ in the western area of Lower Saxony, cluster (A); or lower global values for LSI_m and slightly higher values of $P.ICrops_m$ in the eastern cluster of municipalities, cluster (B). LSI_m, livestock density expressed as livestock units per hectares of Utilized Agricultural Area (ha.UAA); $P.ICrops_m$, share of intensive crops per municipality, expressed as the percentage (%) of total area occupied by crops more prone to be under intensive farming practices.

Table 4. Results from the grouping analysis targeting farmlands more likely to be High Nature Value farmlands (HNVf) in Lower Saxony. *n*, stands for the number of municipalities; *n.a.*, not applicable. Mean, minimum (Min), maximum (Max) and standard deviation (SD) values are presented. R^2, reflects the discriminating ability of each individual variable, which is higher for larger values. Share values depict the ratio between groups (HNVf1 and HNVf2; HNVf2, and non-HNVf) and full area (Eastern Lower Saxony) range values for indicators. HNVf type refers to the classification of areas delineated within each cluster according to their overall characteristics. HNVf1 and HNVf2, stand for High Nature Value farmlands types 1 or 2, respectively. Non-HNVf refer to farmlands that do not exhibit characteristics that convey a high nature value.

	n	**Code and units**	**Mean**	**SD**	**Min**	**Max**	R^2	
Full area		P.ICrops$_m$ (%)	0.50	0.22	0.050	0.99	0.66	
		SEI$_m$ *(n.a.)*	0.44	0.074	0.20	0.63	0.47	
		LSI$_m$ (LSU per ha/UAA)	0.37	0.24	0.00	1.18	0.23	
		DT$_m$ (ha)	4.39	2.90	0.00	13.30	0.18	
Grouping	n	Code and Units	Mean	SD	Min	Max	Share (%)	HNVf type
(a)	163	P.ICrops$_m$ (%)	0.69	0.15	0.15	0.99	0.89	Non HNVf
		SEI$_m$ *(n.a.)*	0.39	0.057	0.23	0.55	0.73	
		LSI$_m$ (LSU per ha/UAA)	0.23	0.21	0.00	0.94	0.80	
		DT$_m$ (ha)	4.10	2.83	0.00	13.3	1.00	
(b)	165	P.ICrops$_m$ (%)	0.30	0.11	0.030	0.64	0.63	HNVf1 and HNVf2
		SEI$_m$ *(n.a.)*	0.50	0.056	0.28	0.62	0.80	

		LSI_m (LSU per ha/UAA)	0.46	0.23	0.050	1.18	0.96	
		DT_m (ha)	5.59	2.71	0.33	12.17	0.89	
(c)	63	$P.ICrops_m$ (%)	0.52	0.13	0.080	0.71	0.67	HNVf2
		SEI_m *(n.a.)*	0.42	0.042	0.20	0.49	0.68	
		LSI_m (LSU per ha/UAA)	0.49	0.18	0.15	0.98	0.70	
		DT_m (ha)	2.05	1.64	0.00	7.72	0.58	

82

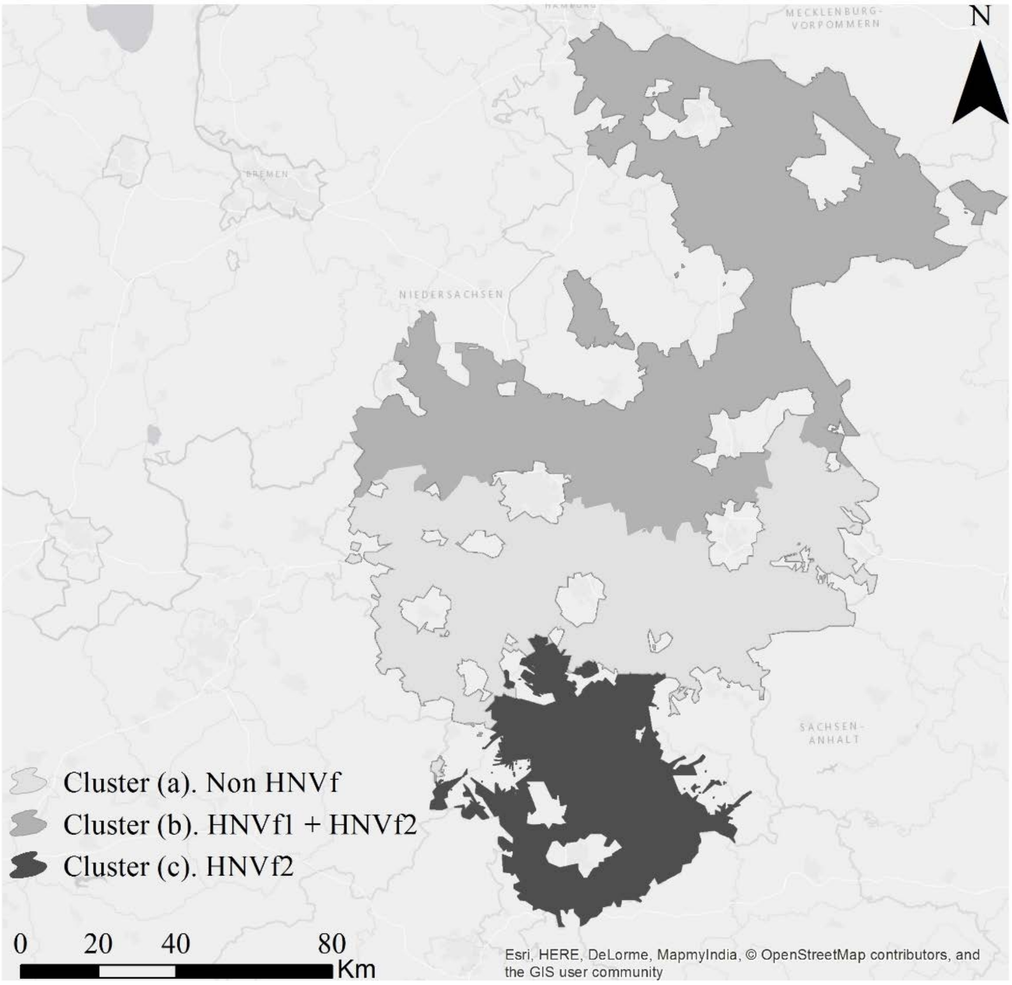

Fig. 4. Delineation of High Nature Value farmlands (HNVf) potential areas in Eastern Lower Saxony, based on grouping analysis on spatially-explicit indicators informing on the intensity of farming practices, landscape elements and crop diversity. HNVf, High Nature Value farmlands; HNVf1, High Nature Value farmlands type 1; HNVf2, High Nature Value farmlands type 2.

Table 5. Variation observed within each indicator considered at the physical block level for farmlands potentially supporting both High Nature Value farmlands types 1 and 2 (HNVf1 + 2), or only High Nature Value farmlands type 2 (HNVf2). *pb*, stands for physical block; pb, physical blocks targeted for each HNvf type; *n.a.*, not applicable; SD, standard deviation; Q_1, refers to the first quartile; Q_3, third quartile; IQR, interquartile range; ha UAA, refers to area in hectares of the Utilized Agriculture Area. Values applied as thresholds to include or exclude physical blocks are highlighted as bold.

		Indicators$_{pb}$ /units	**Mean**	**SD**	**Q_1**	**IQR**	**Q_3**	**$_t$pb**	**ha UAA**	
HNVf1 + 2	HNVf1	P.G$_{pb}$ (%)	85.77	25.68	**83.41**	16.59	100.00	5024	27,214.94	75,127.42
		P.GAES$_{pb}$ (%)	19.47	36.595	0.00	9.93	**9.93**			
	HNVf2	SEI$_{pb}$ *(n.a.)*	0.45	0.19	0.39	0.19	**0.58**	9884	47,912.48	
		P.ICrops$_{pb}$ (%)	0.19	0.34	0.00	0.24	**0.24**			
HNVf2		SEI$_{pb}$ *(n.a.)*	0.42	0.11	0.38	0.11	**0.49**	5542		17,841.68
		P.ICrops$_{pb}$ (%)	0.37	0.43	0.00	0.88	**0.88**			
							Total HNVf			**92,969.10**

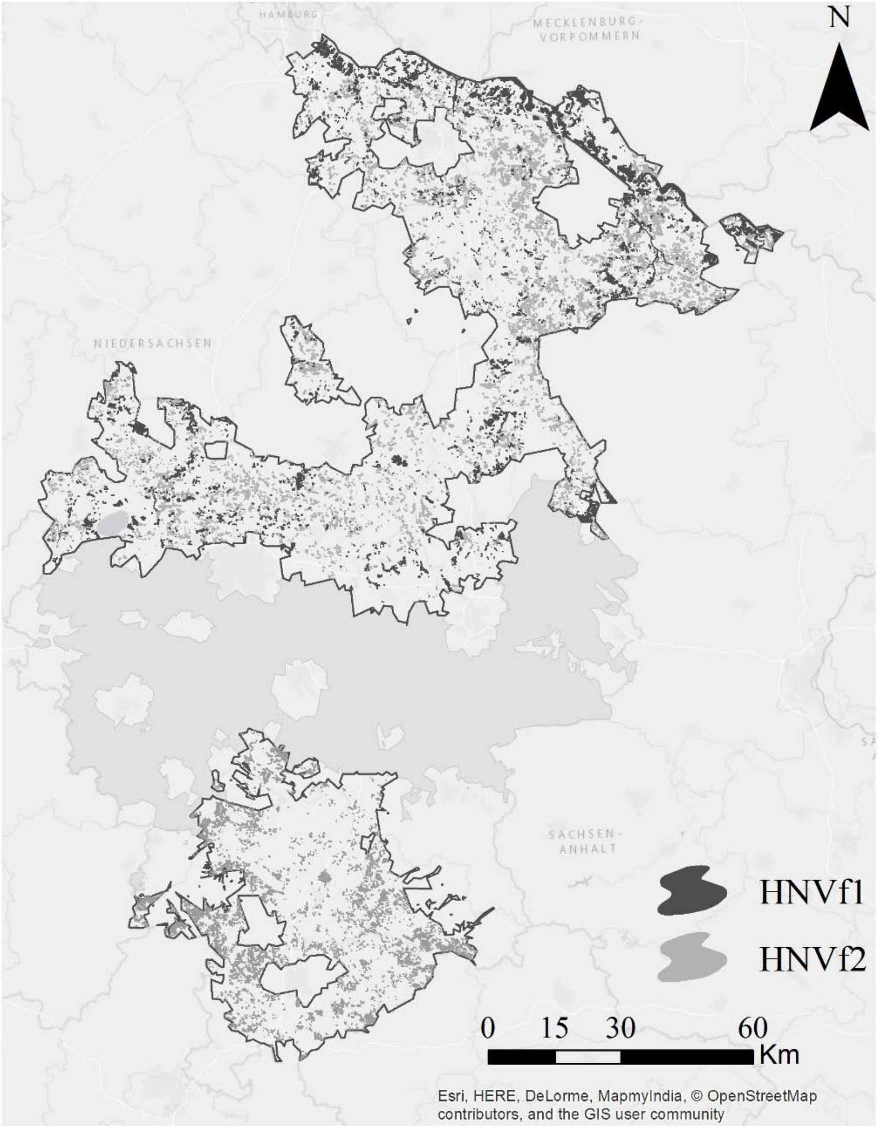

Fig. 5. Fine-scale mapping of High Nature Value farmlands (HNVf) in Lower Saxony at the physical block level. To assure privacy and protection of land owners and managers geometries are not disclosed. HNVf1, High Nature Value farmlands type 1; HNVf2, High Nature Value farmlands type 2.